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April 20, 2017

VIA ELECTRONIC DELIVERY

Marlene H. Dortch
Secretary
Federal Communications Commission
445 12th Street S.W.
Washington, DC 20554

Re: Notice of Ex Parte Presentation
GN Docket No. 14-177; IB Docket No. 15-256; RM-11664; WT Docket No. 10-112; IB Docket No. 97-95

Dear Ms. Dortch:

On Tuesday, April 18, 2017, representatives of Nextlink Wireless, LLC ("Nextlink") met with representatives of the FCC's Wireless Telecommunications Bureau ("WTB"), Office of Engineering and Technology ("OET") and International Bureau ("IB") to discuss Nextlink's Petition for Reconsideration or, in the Alternative, Clarification of the FCC's *Report and Order*, and comments and reply comments in response to the FCC's *Further Notice of Proposed Rulemaking* in the above-referenced proceedings.[1] Attending the meeting on behalf of Nextlink were: Lisa Youngers, Nextlink's Chief Executive Officer; Eric Miller, Nextlink's Chief Technology Officer; and Kaete Demro, Director, Legal and Regulatory for Nextlink (by phone); Michele Farquhar, Tom Peters and C. Sean Spivey of Hogan Lovells US LLP, advisors to Nextlink; and Mike Lasky of Widelity, Inc., consultant to Nextlink. The FCC participants were Jose Albuquerque (IB), Simon Banyai (WTB), Michael Ha (OET, by phone), Ira Keltz (OET), Julius Knapp (OET), John Schauble (WTB), Catherine Schroeder (WTB, by phone), Blaise Scinto (WTB), and Joel Taubenblatt (WTB).

Nextlink commended the FCC for acting quickly to adopt flexible use rules for several bands of millimeter-wave band spectrum, including a portion of the 28 GHz band. Nextlink expressed concern, however, that the new UMFU service rules and the segregation of the 28 GHz A1 band were established well before the characteristics of (much less standards for) fifth-generation ("5G") service have taken form and may not serve as an optimal platform for innovation or investment.

[1] *See* Comments of Nextlink Wireless, LLC, GN Docket No. 14-177, *et al*. (filed Sept. 30, 2016) ("FNPRM Comments"); Reply Comments of Nextlink Wireless, LLC, GN Docket No. 14-177, *et al*. (filed Oct. 31, 2016) ("FNPRM Reply Comments"); Petition for Reconsideration or, in the Alternative, Clarification of Nextlink Wireless, LLC, GN Docket No. 14-177, *et al*. (filed Dec. 14, 2016) ("Pet. for Recon.").

Nextlink focused on four issues in the meeting: (1) allocating the remaining portions of the LMDS band for Upper Microwave Flexible Use ("UMFU") service; (2) performance requirements for UMFU and LMDS band licenses; (3) satellite sharing issues in the A1 band portion of the 28 GHz band; and (4) other UMFU technical service rules. The FCC can improve the prospects for economies of scale, diverse use cases, and innovation and investment in the LMDS band by harmonizing the service rules among the various segments of the LMDS band and reducing the total number of geographic license areas adopted for the band.

Allocating the Remaining Portions of the LMDS Band for UMFU Service

Nextlink urged the FCC to adopt flexible use rules for the LMDS A2 and A3 bands and B block to align the entire LMDS band for flexible use service.

Nextlink noted that several commenters agree that the A3 band and B block are suitable candidates for flexible use rules.[2] Importantly, the record shows that millimeter-wave bandwidths smaller than 500 megahertz will support 5G flexible use cases.[3] Indeed, the FCC has proposed allocating the 24 GHz band for UMFU service, including a 200-megahertz segment of that band.[4] Nextlink recounted that some service providers use combined segments of the LMDS band to provide point-to-point and point-to-multipoint service, and that not including the full LMDS band under Part 30 will lead to regulatory confusion and stranded band segments. Meanwhile, manufacturers currently producing LMDS equipment can include the entire LMDS band into a single integrated radio at marginal costs.[5]

Nextlink discussed findings from a new technical study on coexistence of 5G mobile service with Radio Astronomy Service ("RAS"), Earth Exploration Satellite Service ("EESS") and Space Research Service ("SRS") in the adjacent 31.3-31.8 GHz band (the study is attached here but was not circulated at the meeting).[6] The Reed Engineering Study uses the ITU standard interference thresholds and determines that circular exclusion zones with radii of about 22 miles each would adequately protect RAS from 5G transmissions under worst-case assumptions.[7] Likewise, applying the exclusion zone radii suggested in the Reed Engineering Study would not diminish mobile 5G deployment in a significant way, with only 12 RAS sites currently operating in the United States. The Reed Engineering Study further concludes that the FCC-proposed Out-of-Band Emission ("OOBE") limits are adequate to protect EESS and SRS in practical 5G deployment scenarios.[8] According to the Reed Engineering Study, more than 660,000 macro-cells would need to be deployed in a 200 square kilometer area to exceed the ITU standard interference threshold for EESS.[9] Further, "more

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[2] *See* FNPRM Reply Comments at 5-6 (citations omitted).

[3] *See, e.g.*, Comments of Ericsson Inc., GN Docket No. 14-177, *et al*. at 37 (filed Jan. 15, 2015).

[4] *See* FNPRM Comments at 6 (citations omitted).

[5] *See* Comments of XO Communications, LLC, GN Docket No. 14-177, *et al*. at 11-16 (filed Jan. 28, 2016); Reply Comments of XO Communications, LLC, GN Docket No. 14-177, *et al*. at 4-6 (filed Feb. 26, 2016).

[6] *See* REED ENGINEERING, CO-EXISTENCE OF 5G MOBILE SERVICE AND RAS, EESS, AND SRS AT 31 GHZ (Apr. 2017), *attached hereto* as Exhibit A (the "Reed Engineering Study").

[7] *Id.* at 1.

[8] *Id*.

[9] *Id*. This number of macro cells within the measurement area would require an unrealistically small cell radius of about 34 meters. *Id.* at 9.

than 4.75 billion low-power small cell Base Station transmitters or Mobile Stations in a 200 square kilometer surface area can be easily supported without causing any harmful interference to an EESS receiver."[10] Therefore, the Reed Engineering Study concludes that 5G operations pose no practical threat of interference to RAS, EESS or SRS.[11]

Similarly, the FCC should include the A2 band in its UMFU service rules. The LMDS band works together as a whole, and applying a piecemeal licensing and operating scheme to the band will harm the A2 band's utility. Under the 28 GHz European band plan, the A2 spectrum pairs with an equally sized uplink block in the Upper A1 band.[12] The European band plan's configuration guarantees that equipment will be available that can support next-generation fixed use cases that involve both the A1 and the A2 bands. Current LMDS use cases are expected to play a major role in moving toward future 5G deployments, and separating the A1 and A2 bands could stifle existing deployment scenarios and new deployments. Nextlink noted that it would continue to protect incumbent feeder link operations in the A2 band once the FCC allocates the spectrum for UMFU service, consistent with existing rules.[13] Alternatively, if the FCC strands the A2 band, then new entrants that only bid on and win an "Upper 28 GHz A1 Band" license based on the existing equipment ecosystem may discover that no equipment exists to operate solely over that spectrum.[14] New entrants that fail to appreciate this issue may purchase spectrum licenses subject to an uncertain equipment ecosystem.

Not adopting uniform mobile service rules for the remaining portions of the LMDS band will likely orphan this spectrum and potentially create regulatory confusion regarding performance requirements throughout the current LMDS band. Likewise, new UMFU licensees will be deprived of the economies of scale from technology suitable for the full LMDS band, and the remaining A2 and A3 band and B block licenses could languish in the FCC's spectrum inventory. Keeping the remaining segments of the LMDS band in the FCC's spectrum inventory significantly undermines the likelihood that this spectrum will be put to its highest and best use in the future. Nextlink therefore urged the FCC to adopt the equivalent of a "dig once" policy for this spectrum by allocating the remaining portions of the LMDS band for UMFU service and adopting a single, unified performance deadline for the entire band (even if the remaining band segments are not allocated for UMFU service).

<u>Performance Requirements for LMDS Band Licenses</u>

In addition to allocating the remaining segments of the LMDS band for UMFU service, Nextlink noted that revisiting the geographic license areas and performance requirements for the LMDS band will ensure that the band becomes a platform for stronger innovation and investment. Nextlink urged the FCC to re-harmonize the LMDS band by creating regulatory parity among new entrants and incumbent licensees, as well as across LMDS band segments, by assigning UMFU rights to the entire band and adopting the same performance deadlines across the LMDS band for all licensees.[15]

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[10] *Id*. at 1.

[11] *Id*. at 8-11.

[12] *See* Exhibit B at 1, *attached hereto*.

[13] *See* 47 C.F.R. §§ 101.147(y).

[14] New entrants would face a parallel risk if they fail to secure both the Upper 28 GHz A1 Band and Lower 28 GHz A1 Band licenses in a market area.

[15] *See* Exhibit B at 2, *attached hereto*.

Nextlink briefly recounted the historical opposition to county-based licensing in this proceeding,[16] and its preference for larger geographic license areas, such as Basic Trading Areas ("BTAs") or Partitioned PEAs.[17] Nextlink added that the three regulatory requirements that most affect investment and deployment of new spectrum-based services are (1) geographic license area size; (2) performance requirement metrics and (3) performance requirement deadlines. If the FCC maintains small, county-based geographic license areas then it must ease the performance requirement metrics and deadlines to ensure deployment across counties, especially in less densely populated areas.[18]

Nextlink explained that the June 2024 performance deadline for incumbent UMFU licensees is too onerous and that incumbents may be unable to meet the deadline based on delayed development of 5G mobile technology.[19] As Nextlink has previously noted, standards for 5G are unlikely to become available until 2020 or 2021.[20] Meanwhile, the state of the art of several components of 5G technology, including beamforming and antenna form factor, must advance significantly for next-generation mobile networks to become viable. Extending incumbent licensees' performance deadlines will not give them any advantage over new UMFU licensees because these new county-based licenses will require significant construction by incumbents and new licensees alike after compatible radio equipment becomes available. The FCC can provide relief to incumbent licensees—and ensure greater collaboration among all UMFU licensees—by aligning their performance deadlines with the same deadlines set for new licensees following an UMFU spectrum auction. As noted above, Nextlink also urged the FCC to adopt a uniform performance deadline for all UMFU licenses as well as the remaining portions of the LMDS band, regardless of whether the remaining portions of the LMDS band are allocated for UMFU service, given the ongoing interrelated aspects of the LMDS band.

Nextlink further noted that population-based performance metrics are inappropriate for tribal, state and federal lands.[21] Nextlink encouraged the FCC to follow the precedent it set when it adopted service rules for the 700 MHz Band and carve-out these areas from performance

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[16] *See, e.g.*, Comments of 4G Americas, GN Docket No. 14-177, *et al*. at 7-8 (filed Jan. 27, 2016); Comments of AT&T, GN Docket No. 14-177, *et al*. at 13 (filed Sept. 30, 2016); Comments of Blooston Rural Carriers, GN Docket No. 14-177, *et al*. at 2 (filed Jan. 31, 2017); Petition for Reconsideration of Competitive Carriers Association, GN Docket No. 14-177, *et al*. at 9 (filed Dec. 14, 2016); Reply Comments of Intel Corp., GN Docket No. 14-177, *et al*. at 5 (filed Feb. 26, 2016); Comments of Nokia, GN Docket No. 14-177, *et al*. at 18 (filed Jan. 27, 2016); Comments of Qualcomm Inc., GN Docket No. 14-177, *et al*. at 8-9 (filed Jan. 27, 2016); Comments of the Rural LMDS Licensees, GN Docket No. 14-177, *et al*. at 4 (filed Dec. 14, 2016); Comments of Samsung Electronics America Inc. and Samsung Research America, GN Docket No. 14-177, *et al*. at 6 (filed Sept. 30, 2016); Comments of Skyriver Communications Inc., GN Docket No. 14-177, *et al*. at 8 (filed Jan. 27, 2016); Comments of Verizon, GN Docket No. 14-177, *et al*. at 10 (filed Jan. 28, 2016).

[17] *Ex Parte* Letter from Michele C. Farquhar, Counsel to Nextlink and XO Communications, LLC to Marlene H. Dortch, Secretary, FCC, GN Docket No. 14-177, *et al*. (filed June 8, 2016).

[18] As one example of the drastic difference between BTA- and county-based licensing, the geographic territory of the State of Texas is made up of 254 counties compared to just 32 BTAs. *See* Exhibit B at 3, *attached hereto*.

[19] *See* FNPRM Reply Comments at 18; Pet. for Recon. at 8-11.

[20] *See* Pet. for Recon. at 8-9.

[21] *See* FNPRM Comments at 29-30; Pet. for Recon. at 6-7.

requirements—particularly in light of the FCC's move towards smaller geographic license area sizes.[22] In addition, Nextlink reviewed the disadvantages of adopting untested "use-or-share" rules for the LMDS spectrum as well as performance benchmarks based on "actual use" of 5G service.[23]

Satellite Sharing Issues in the A1 Band of the 28 GHz Band

Nextlink also addressed recent calls from some segments of the satellite industry to create *de facto* primary rights in the 28 GHz band.[24] Nextlink explained that the FCC's existing rules adequately protect FSS operators and provide sufficient access to spectrum in the band—where FSS is a secondary service. These satellite companies' various petitions for reconsideration and their latest proposal to change the rules for accessing the 28 GHz band will undermine 5G deployments and are contrary to the FCC's longstanding secondary market policies.

For example, the satellite companies propose upwardly adjusting the aggregate permitted interference population limit from 0.1 percent to 0.2 percent in counties with a population of greater than 300,000 people.[25] Upwardly adjusting the population coverage limit in the most densely populated license areas would potentially deny the benefits of terrestrial-based 5G services to thousands of people; the satellite companies' proposal would affect approximately 10,000 POPs in Los Angeles County alone.[26] The satellite companies propose even larger population thresholds in less densely populated counties.[27]

Nextlink further discussed how the satellite companies' proposed definitions of certain terms related to transient population centers would cripple 5G network deployments in locations where this service will likely prove most essential. As one example, defining a "major event venue" as one with a capacity of 10,000 people or more, as the satellite companies have proposed,[28] could negatively affect deployments in and around smaller high school and college stadiums and concert venues. Similarly, limiting the definition of a "passenger railroad" to railroad track operated by Amtrak (as the satellite companies propose)[29] would exclude many of the country's major railroads, including most regional commuter railroads.

[22] *See* FNPRM Comments at 29, n.83 (*citing Serv. Rules for the 698-746, 747-762 & 777-792 MHz Bands Revision of the Commission's Rules to Ensure Compatibility with Enhanced 911 Emergency Calling Sys. Section 68.4(a) of the Commission's Rules Governing Hearing Aid-Compatible Telephones Biennial Regulatory Review -- Amendment of Parts 1, 22, 24, 27, & 90 to Streamline & Harmonize Various Rules Affecting Wireless Radio Servs. Former Nextel Commc'ns*, Second Report and Order, 22 FCC Rcd. 15289, 15350 ¶ 160 (2007)).

[23] *See* FNPRM Comments at 20-28; FNPRM Reply Comments at 20-26.

[24] *See, e.g.*, *Ex Parte* Letter from EchoStar Satellite Operating Corp. and Hughes Network Sys., LLC, Inmarsat, Inc., WorldVu Satellites Ltd., d/b/a OneWeb, SES Americom, Inc., O3b Limited, Intelsat Corp. and The Boeing Co. to Marlene H. Dortch, Secretary, FCC, GN Docket No. 14-177, *et al*. (filed Mar. 31, 2017) ("*Satellite Companies Proposal*").

[25] *Id.* at 5.

[26] *See* U.S. Census Bureau, Los Angeles County, California QuickFacts, https://www.census.gov/quickfacts/table/PST045216/06037,00 (last visited Apr. 19, 2017).

[27] *Satellite Companies Proposal* at 5.

[28] *Id.* at 6.

[29] *Id*.

Nextlink urged the FCC to maintain existing limits on FSS earth station operations in transient population areas, to keep its limit of three FSS earth stations per county for the 28 GHz band and to reject application of the tiered-access approach proposed for the 70, 80 and 90 GHz bands to the UMFU bands as well. The satellite companies' proposal for expanded access to the 28 GHz band is contrary to the FCC's longstanding secondary market policies. Instead, satellite operators should rely on traditional means to access millimeter-wave spectrum—such as spectrum auctions and secondary market transactions—should they actually need it.

UMFU Technical Requirements that May Hamper Development of 5G Technologies

Finally, Nextlink discussed a few discrete UMFU technical rules proposed in the *Further Notice* that, if adopted, could hamper development of 5G technologies.[30] First, Nextlink explained that downward scaling of maximum power limits for mobile and transportable stations is unnecessary because specific absorption rate ("SAR") limits will likely determine the maximum power limits for mobile devices.[31] Second, Nextlink noted that the current UMFU border-coordination criteria are overly burdensome in light of the smaller, county-based market sizes and should not be based on distance alone.[32] The FCC should change the coordination criteria at market borders for fixed, point-to-point operations to the extent the agency maintains county-based license areas.[33] Third, Nextlink argued that the FCC can encourage innovation and experimentation by network operators and equipment vendors by refraining from adopting antenna height or downtilt mandates.[34] And fourth, Nextlink urged the FCC to clarify that its "operability" requirement does not apply retroactively to equipment that operators have already deployed across segments of spectrum included in the new UMFU service rules, such as the LMDS band.[35] Nextlink urged the FCC to make clear that the operability rules will not require a device to meet conflicting rules if they arise in a particular band.[36]

[30] *See* FNPRM Comments at 30-31; FNPRM Reply Comments at 28-34.

[31] *See* FNPRM Comments at 30; FNPRM Reply Comments at 29-31.

[32] *See* FNPRM Comments at 30-31; FNPRM Reply Comments at 31-32.

[33] *See id.*

[34] *See* FNPRM Reply Comments at 28-29.

[35] *See id.* at 33-34.

[36] *See id.*

Pursuant to Section 1.1206(b) of the Commission's rules, I am filing this letter electronically in the above-referenced dockets. Please contact me directly with any questions.

Respectfully submitted,

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Co-existence of 5G Mobile Service and RAS, EESS, and SRS at 31 GHz

Reed Engineering
April 2017

This whitepaper addresses the coexistence of 5G mobile service in 31 GHz to 31.3 GHz spectrum with Radio Astronomy Service (RAS), Earth Exploration Satellite Service (EESS), and Space Research Service (SRS) in the adjacent 31.3 to 31.8 GHz spectrum.

Summary: The paper summarizes the size of the exclusion zone or protection zone for the RAS for various practical scenarios and concludes that circular exclusion zones with the radius of about 22 miles would adequately protect the RAS from 5G transmissions.[1] An exclusion zone of this size would ensure that the aggregate signal from 5G macro cell base stations at the RAS receiver will not exceed the ITU interference threshold, facilitating harmonious coexistence between 5G mobile service and RAS. The paper also quantifies the number of 5G transmitters that can be accommodated by EESS and SRS (e.g., 660,000 to 1.3 million high-power Base Station transmitters per 201 km^2) and concludes that the FCC-proposed Out-Of-Band-Emission (OOBE) limits can adequately protect EESS and SRS in practical 5G macro cell deployment scenarios.

The aggregate power from 10,000 small cells would require an even smaller exclusion zone than what is needed for macro cells to protect RAS. In addition, more than 4.75 billion low-power small cell Base Station transmitters or Mobile Stations in a 201 square kilometer surface area can be easily supported without causing any harmful interference to an EESS receiver. The analysis finds that as many as 250 simultaneously transmitting Mobile Stations in an outdoor macro cell can be supported without causing harmful interference to an RAS receiver. Many more than 250 cell-edge Mobile Stations can be supported in the case of outdoor and indoor small cell deployments.

Note that the analysis performed in this paper assumes the worst-case interference scenario, where the path between a 5G Base Station or Mobile Station transmitter and a receiver is unobstructed by intervening objects such as vegetation and buildings. Hence, exclusion zones smaller than those predicted here would suffice to protect RAS in practice, and, more 5G transmitters (i.e., Base Stations and Mobile Stations) than those predicted here can be supported while protecting EESS and SRS in practice.

Organization: The whitepaper is organized as follows:

- Section I briefly describes interference scenarios around 31 GHz.
- Section II summarizes the analysis approach, lists major assumptions, and identifies enhancements to the analysis approach and/or assumptions.
- Section III provides conclusions of the interference analysis in the case of cellular base stations serving as 5G transmitters.
- Section IV analyzes the interference scenarios in the case of mobile stations serving as 5G transmitters and estimates the number of simultaneously transmitting mobile stations that can be supported in the exclusion zone around an RAS receiver.
- Section V discusses interference mitigation techniques that further enable harmonious coexistence between 5G mobile services and RAS, EESS, and SRS.

[1] Details on RAS receiver locations are contained in Appendix I.

I. Interference Scenarios Around 31 GHz

The FCC is targeting the use of certain portions of the millimeter-wave spectrum to facilitate and accelerate the emerging fifth-generation (5G) wireless services as part of Upper Microwave Flexible Use Service (UMFUS).[2] UMFUS will spur innovations and benefit consumers. One of the UMFUS spectrum bands is LMDS spectrum with A and B blocks. The A Block consists of three sub bands: (i) the A1 band ranging from 27.50 GHz to 28.35 GHz; (ii) the A2 band ranging from 29.10 GHz to 29.25 GHz; and (iii) the A3 band ranging from 31.075 GHz to 31.225 GHz. The B Block consists of the B1 band ranging from 31.00 GHz to 31.075 GHz and the B2 band ranging from 31.225 GHz to 31.30 GHz. An entity owning multiple A and B blocks can create a contiguous radio channel with wide bandwidth. For example, the A3, B1, and B2 bands can be combined to create a 300-megahertz wide radio channel that ranges from 31.00 GHz to 31.30 GHz. Nextlink has such contiguous spectrum in large parts of the country, covering about 30 percent of the U.S. population.

The spectrum band adjacent to the B2 band spans from 31.3 GHz to 31.8 GHz and is allocated to Radio Astronomy Service (RAS), Earth Exploration Satellite Service (EESS), and Space Research Service (SRS). The services in this spectrum band are passive; the receivers make observations but there are no active transmitters.[3] The RAS receivers are radio telescopes that are terrestrial. The EESS and SRS receivers are located on non-geostationary satellites. Coexistence of 5G mobile services with RAS, EESS, and SRS is analyzed in this paper.

Radio astronomy has facilitated numerous fundamental astronomical advances such as the discovery of galaxies and the direct measurement of distances of certain external galaxies. Radio astronomical observations help improve our understanding of the Universe and help us investigate some cosmic phenomena. To enable radio astronomers to make useful astronomical observations from the Earth's surface, the International Telecommunication Union (ITU) has defined protection criterion for RAS receivers.[4] According to ITU recommendations, an RAS receiver can be considered to be protected from interference if the amount of interference is (-192 dBW) in 500 megahertz bandwidth at the center frequency of 31.55 GHz.[5] If 5G transmitters are located *sufficiently far* from the RAS receiver (i.e., a radio telescope), the interference caused to the RAS receiver would be below the reference interference threshold of (-192 dBW) per 500 megahertz bandwidth, leading to harmonious coexistence of RAS and 5G mobile services. A circular exclusion zone or protection zone around an RAS receiver can be defined using such reference interference threshold. The *goals of the RAS interference analysis* in this paper are to quantify (i) the size of a circular exclusion zone around an RAS receiver such that multiple high-power 5G base stations of a cellular network surrounding such RAS receiver do not cause detrimental interference to RAS and (ii) the number of low-power 5G mobile stations that can be supported in such exclusion zone without causing detrimental interference to RAS.

The EESS helps observe and study phenomena that influence Earth and its environment. The EESS use sensors on satellites to make useful measurements of atmosphere, land, and sea.[6] These sensors can detect

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[2] *See Use of Spectrum Bands Above 24 GHz For Mobile Radio Services, et al.*, Report and Order and Further Notice of Proposed Rulemaking, 31 FCC Rcd 8014 (2016) ("*Spectrum Frontiers Report & Order*").

[3] *See* 47 C.F.R. § 2.106, nn. US246 and 5.340.

[4] *See Protection criteria used for radio astronomical measurements*, Rec. ITU-R RA.769-2 ("ITU-R RA.769-2").

[5] *Id.* at Table 1.

[6] *See* NAT'L ACADEMIES OF SCIENCES, ENGINEERING & MEDICINE, HANDBOOK OF FREQUENCY ALLOCATIONS AND SPECTRUM PROTECTION FOR SCIENTIFIC USES 103-228 (2nd ed., 2015).

variations in the Earth's environment under all weather conditions. Example measurements made by these sensors include: (i) temperature and humidity in the atmosphere; (ii) moisture, roughness, and biomass on land; and (iii) temperature and surface wave height in the oceans. These measurements help predict weather and severe storms and improve our understanding of changes in global climate. SRS is a radio communication service where spacecraft or other objects in space are used for scientific or technological research purposes.[7] ITU has defined protection criterion for EESS receivers,[8] but no separate protection criterion has been defined by the ITU for SRS. Hence, this paper utilizes the same protection criterion for both EESS and SRS and assumes that the EESS analysis is applicable to the SRS analysis. According to Section 9 of ITU-R SM.2092, an EESS receiver can be considered to be protected from interference if the amount of interference is (-163 dBW) in 100 megahertz bandwidth.[9] If the number of simultaneously active 5G transmitters is *sufficiently small* within the footprint of an EESS satellite, the cumulative interference caused to the passive EESS sensor receiver would be below the reference interference threshold of (-163 dBW) per 100 megahertz bandwidth. Under these conditions, 5G mobile services and EESS and SRS can coexist without 5G mobile services causing harmful interference to EESS and SRS. The *goal of the EESS and SRS interference analysis* in this paper is to quantify the number of 5G transmitters that can be accommodated by EESS and SRS receivers such that 5G transmitters do not cause harmful interference to EESS and SRS.

The analysis focuses on the Out-of-Band-Emission (OOBE) interference caused by a 5G transmitter due to the frequency vicinity of 5G and RAS/EESS systems. Since the interference protection guidelines from ITU are used as the baseline, adherence to these guidelines dictates the amount of interference that can be tolerated by an RAS/EESS receiver. The analysis performed in this paper ensures that the OOBE interference generated by 5G transmitters and experienced by the RAS/EESS receiver stays below such interference power limit. Furthermore, receivers are often designed to operate well above the minimum-performance guidelines. Hence, once such interference limit is adhered to, the RAS/EESS receiver in practice will be able to recover the desired signal.

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[7] *See* Bradford A. Kaufman, *Communicating with SRS and EESS Satellites*, ITU-R ITUR.MANTA Contribution 6 (Aug. 2012), https://www.itu.int/dms_pub/itu-r/md/12/itur.manta/c/R12-ITUR.MANTA-C-0006!!PDF-E.pdf.

[8] *See Studies related to the impact of active services allocated in adjacent or nearby bands on Earth exploration-satellite service (passive)*, Rep. ITU-R SM.2092, Section 9 ("ITU-R SM.2092").

[9] *Id.*

II. Analysis Approach

The key steps for the RAS interference analysis are specified below:

1. Define the target received interference power level in the reference bandwidth at the RAS receiver (i.e., -192 dBW in 500 MHz)[10].
2. Calculate the Effective Isotropic Radiated Power (EIRP) of the 5G Base Station transmitter constrained by the FCC-mandated maximum OOBE levels[11] (i.e., -5 dBm/MHz within 10 percent of the channel edge and -13 dBm/MHz beyond 10 percent of the channel edge).
3. Consider first-tier of interference caused by high-powered macro base stations,[12] receive antenna gain, carrier frequency, free-space path loss, interference threshold from Step 1, and EIRP from Step 1 to estimate the radius of the protection zone surrounding the RAS receiver.

Major parameters used in the RAS interference analysis are listed below:

- Transmit and receive channel bandwidth: 300 megahertz[13]
- Carrier frequency: 31.55 GHz
- Receive antenna gain of the RAS receiver toward a 5G transmitter: -10 dB[14]
- Vegetation loss is not considered in this worst-case interference analysis. Vegetation in the propagation path from a 5G transmitter to an RAS receiver would significantly weaken the interference experienced by an RAS receiver.[15]
- Shadow fading caused by obstructions is not considered in this worst-case interference analysis and could significantly weaken the interference from 5G transmitters. Obstructions such as buildings can cause attenuation of more than 20 dB (e.g., 40 dB to 80 dB due to the construction materials of a building such as bricks, concrete, etc.).[16]
- Line-of-Sight (LOS) propagation is assumed between a 5G transmitter and an RAS receiver in this worst-case interference analysis. Non-LOS (NLOS) propagation would significantly weaken the interference from 5G transmitters. The propagation path loss exponent "*n*" of about 2 is

[10] *See* ITU-R RA.769-2.

[11] *See Spectrum Frontiers Report & Order*.

[12] A typical receiver located in overlapping cell-edge coverage areas of base stations would get interference from about three Base Station transmitters. In practice, RF planning and design can reduce the number of first-tier of interferers from three to zero if needed. The use of three transmitters is a way of modeling an aggregate interference scenario as opposed to a single-transmitter scenario.

[13] The 5G transmitter bandwidth is 300 megahertz when all of A3 band (31.075-31.225 GHz), B1 band (31.00-31.075 GHz), and B2 band (31.225-31.30 GHz) are used.

[14] *See* ITU-R RA.769-2. The gain is specified to be in the range from 32 dBi to -10 dBi. Due to the pointing of the RAS receive antenna relative to the transmit antennas of cellular base stations, -10 dBi gain is considered to be more practical.

[15] A 15 m row of pine trees has been found to cause 24.8 dB attenuation at 35 GHz. *See* Shajahan Kutty & Debarati Sen, *Beamforming for Millimeter Wave Communications: An Inclusive Survey*, 18 IEEE Communication Surveys & Tutorials, No. 2, 949-73 (2016) ("IEEE Beamforming Survey").

[16] *See* Farouq Khan & Zhouyue Pi, *An introduction to millimeter wave mobile broadband systems*, IEEE COMMUNICATIONS MAG., June 2011, at 101-07 ("*Khan & Pi*").

appropriate for LOS propagation and 4.5 is appropriate for NLOS propagation around 28 GHz. A larger *n* corresponds to larger path loss.[17]

- Atmospheric losses are assumed to be zero (worst case).
- Beamforming related parameters:
  - Radio resources undergoing user-specific beamforming: 75 percent (i.e., no beamforming for 25 percent of resources carrying overhead such as Reference Signals used for cell acquisition);
  - Beamforming attenuation toward an RAS receiver (e.g., due to traditional RF design optimization techniques such as antenna down-tilting and azimuth changes and/or null-steering technique implemented by an antenna): -40 dB (as seen from Figure 1, for example)[18]; and
  - Attenuation of overhead signals toward an RAS receiver: -15 dB[19]. Note that a typical Base Station antenna is down-tilted by a few degrees relative to horizon and results in attenuation toward horizon. Since the antenna beam-width is quite small (e.g., 5° to 15°) in the vertical plane, there is sharp attenuation in the vertical plane away from the antenna boresight.
- Small-cell related parameters:
  - Small cell EIRP: 37 dBm[20] (or 5 W) in 300 megahertz
  - In-band to out-of-band power ratio[21]: 60 dB
  - OOBE: -48 dBm per MHz[22]

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[17] *See generally* SHU SUN, *ET AL.*, INVESTIGATION OF PREDICTION ACCURACY, SENSITIVITY, AND PARAMETER STABILITY OF LARGE-SCALE PROPAGATION PATH LOSS MODELS FOR 5G WIRELESS COMMUNICATIONS, 65 IEEE TRANSACTIONS ON VEHICULAR TECHNOLOGY 2843 (May 2016).

[18] Such assumption is conservative. Three-dimensional arrays can also provide significantly better sidelobe reduction, although the third dimension will not reduce beam width directly. In addition to Figure 1, for more examples and with realistic hardware impairments *see also* OMAR MOHAMMED BAKR, A SCALABLE AND COST EFFECTIVE ARCHITECTURE FOR HIGH GAIN BEAMFORMING ANTENNAS, Technical Report No. UCB/EECS-2010-178 (Dec. 23, 2010) (Ph.D. Dissertation, Dept. of Computer Science, Univ. of California, Berkeley), https://www2.eecs.berkeley.edu/Pubs/TechRpts/2010/EECS-2010-178.pdf ("Berkley Technical Report").

[19] This is an example value. Examples of 2-D array beam pattern properties can be found in the Berkley Technical Report. An RF design may decide to reduce the sector size or even eliminate a sector facing the RAS receiver.

[20] A small cell aims for a much smaller footprint compared to macro cells. This power level is an example power level and small cells in practice would have different power levels. For example, the power level can be 250 mW for a local area BS and 6.3 W for a medium range BS. *See* Small Cell Forum, *Simplifying small cell installation: Harmonized principles for RF compliance*, Document No. SCF 182.09.01 at Tables 3-1 and 3-2 (Feb. 2017); *see also Khan & Pi*; Antonio Puglielli *et al.*, *Design of Energy- and Cost-Efficient Massive MIMO Arrays*, 104 Proceedings of the IEEE 586-606 (2016); Sonia Gimenez, Sandra Roger, Paolo Baracca, David Martín-Sacristán, Jose F. Monserrat, Volker Braun & Hardy Halbauer, *Performance Evaluation of Analog Beamforming with Hardware Impairments for mmW Massive MIMO Communication in an Urban Scenario*, 16 Sensors No. 10, 1555 (2016).

[21] This is based on the FCC-allowed transmit power of 75 dBm per 100 megahertz (i.e., 55 dBm/MHz in-band transmission power) and OOBE of -5 dBm/MHz just outside the channel edge. These FCC-proposed power levels imply that the in-band power to out-of-band power ratio is 55 – (-5) = 60 dB. Potential waveforms being discussed for 5G include Filter Bank Multi Carrier (FBMC) and Universal Filtered Multicarrier (UFMC). These waveforms and suitable baseband and RF filtering can help achieve this level of out of band rejection. *See* Sunao Ronte, Masaaki Fuse & Ken Shiori, *New Waveform Signal Analysis*, Anritsu Technical, No. 91, 31-42 (2016), http://dl.cdn-anritsu.com/ja-jp/test-measurement/reffiles/About-Anritsu/R_D/Technical/91/91-04-5g-2.pdf ("Anritsu Waveform Analysis"); Baltar, Leonardo G., Dirk S. Waldhauser, & Josef A. Nossek, *Out-of-band radiation in multicarrier systems: a comparison*, Multi-Carrier Spread Spectrum 2007, 107-16 (2007) ("*Baltar & Waldhauser*").

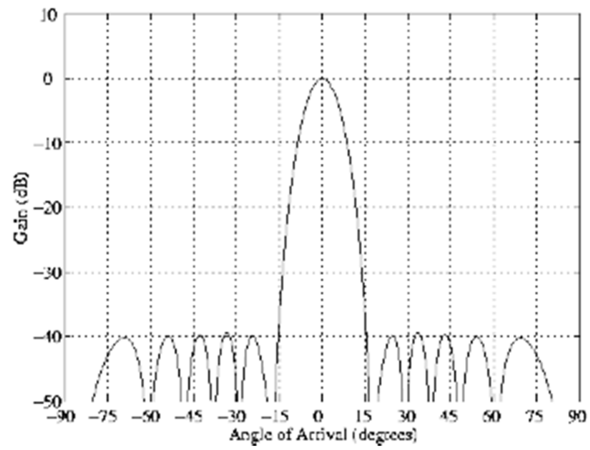

Figure 1. Theoretical Uniform Linear Array with Hanning Window Applied Across 16 Elements. ***(Additional elements can be used to narrow the array beam and reduce sidelobe levels with appropriate weighting.)***

The key steps for the EESS interference analysis are specified below:

1. Define the target received interference power level in the reference bandwidth at the EESS receiver (i.e., -163 dBW in 100 MHz).
2. Calculate the EIRP of the 5G Base Station transmitter using FCC-mandated OOBE levels (i.e., -5 dBm/MHz within 10 percent of the channel edge and -13 dBm/MHz beyond 10 percent of the channel edge).
3. Determine free-space path loss between the 5G transmitter and the EESS satellite receiver using receive antenna gain, carrier frequency, and satellite altitude.
4. Calculate the power received at the satellite from a single 5G transmitter.
5. Calculate the maximum allowed interference power in the target receiver bandwidth based on reference interference threshold from Step 1 and target receiver bandwidth.
6. Consider the received power from a single transmitter from Step 4 and the maximum allowed interference power from Step 5 to estimate the number of simultaneous transmitters that can be supported.

Major parameters used in the EESS interference analysis are listed below:

- Transmit and receive channel bandwidth: 300 megahertz
- Carrier frequency: 31.55 GHz
- Receive antenna gain of the EESS receiver toward a 5G transmitter: 45 dB[23]
- Satellite altitude: 850 km[24]
- Surface area[25] on the Earth covered by the EESS satellite's sensor pixel: 201 km^2

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[22] OOBE in 300 megahertz bandwidth is (37 dBm – 60 dB = -23 dBm) or (-23 dBm – 10*$\log_{10}$(300) = -48 dBm/MHz).

[23] *See* ITU-R SM.2092 at Section 9.

[24] *See id.*

- Beamforming related parameters:
  - o Radio resources undergoing user-specific beamforming: 75 percent (i.e., no beamforming for 25 percent of resources carrying overhead such as Reference Signals)
  - o Beamforming attenuation toward an EESS receiver: -40 dB[26]
  - o Attenuation of overhead signals toward an EESS receiver: -15 dB

[25] *See id.*

[26] The attenuation levels used in this case of EESS receivers are the same as those used for the RAS interference analysis. Since an RAS receiver is terrestrial, while an EESS receiver is on a satellite, higher attenuation levels are expected for an EESS receiver and actual interference experienced by an EESS receiver would be less than the amount of interference assumed in this analysis.

III. Summary of the Interference Analysis: 5G Base Stations as Transmitters

A given RAS receiver may see interference from three base stations for a traditional macro cellular deployment with 120-degree sectorization. Table 1 summarizes the results of the RAS analysis when three Base Station transmitters are simultaneously active and causing interference to an RAS receiver. 5G deployments could also include numerous small cells. The cases for 100, 1,000, and 10,000 small cell transmitters are also shown in Table 1.

Table 1. Exclusion Zone Around an RAS Receiver for Multiple Simultaneous 5G Base Station Transmitters[27]

Scenario	RAS Receiver Channel Bandwidth (MHz)	Maximum Allowed Interference Power in Receive Bandwidth (dBm)	Effective OOBE EIRP of a 5G Transmitter in Receive Bandwidth (dBm)	Radius of an Exclusion Zone (km)	Radius of an Exclusion Zone (miles)
Three Macro Cells (beamforming, 5G RF optimization)	200	-165.98	-7.17	36.1	22.4
	300	-164.22	-6.74	31.0	19.3
	500	-162.00	-6.27	25.3	15.8
100 Small Cells (beamforming and RF optimization)	500	-162.00	-41.77	2.4	1.5
1,000 Small Cells (beamforming and RF optimization)	500	-162.00	-41.77	7.8	4.8
10,000 Small Cells (beamforming and RF optimization)	500	-162.00	-41.77	24.6	15.3

Based on the results summarized in Table 1, ***an exclusion zone with a radius of about 36 kilometers (22 miles) around an RAS receiver would adequately protect an RAS receiver from a 5G mobile network***. ***We further note that smaller exclusion zones would be adequate in practice due to the worst-case interference scenario assumed in the analysis.*** Note that the analysis shown here assumes the worst-case interference scenario, where the path between a 5G transmitter and an RAS receiver is unobstructed by intervening objects such as vegetation and buildings and experiences no additional losses due to moisture in the atmosphere. In practice, these objects would significantly weaken the actual interference experienced by an RAS receiver. For example, interference from a 5G transmitter could easily attenuate by 20 dB to 30 dB (i.e., 100 to 1,000 times weaker) due to the presence of such intervening objects. Hence, exclusion zones smaller than those predicted here would suffice in practice. Additionally, the requirement of such exclusion zones can be met easily because RAS receivers are often located away from population centers.[28]

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[27] Detailed calculations of the values shown in Table 1 using the steps outlined above are contained in Appendix II.

[28] *See* App. I.

Table 2 summarizes the results of the EESS analysis for 5G transmitters in different scenarios.

Table 2. Supportable Number of 5G Transmitters while Protecting an EESS Receiver[29]

Scenario	EESS Receiver Channel Bandwidth (MHz)	Maximum Allowed Interference Power in Receive Bandwidth (dBm)	Effective OOBE EIRP of a Single 5G Transmitter in Receive Bandwidth (dBm)	Interference Power in Receive Bandwidth due to a Single Transmitter (dBm)	Maximum Number of Transmitters in 201 km^2 Satellite Beam	Implied Cell Radius of a Hexagonal Cell (m)
Macro Cells (beamforming, 5G RF optimization)	200	-129.99	-7.17	-188.18	659,968	10.8
	300	-128.23	-6.74	-187.75	895,620	9.3
	500	-126.01	-6.27	-187.28	1,339,737	7.6
Small Cells (beamforming and RF optimization)	200	-129.99	-45.75	-226.76	4.75 billion	0.13
	300	-128.23	-43.99	-225.00	4.75 billion	0.13
	500	-126.01	-41.77	-222.78	4.75 billion	0.13

Based on the results summarized in Table 2, ***about 660,000 to 1.3 million high-power Base Station transmitters in an approximately 200 square kilometer surface area can be easily supported without causing any harmful interference to an EESS receiver***. **Furthermore,** ***about 4.75 billion low-power small cell Base Station transmitters in a 200 square kilometer surface area can be easily supported without causing any harmful interference to an EESS receiver.***[30]

Mobile Stations have much less power than macro Base Stations and even small cells. For example, while a small cell may have 37 dBm maximum transmit power, a Mobile Station typically has the maximum transmit power of only 23 dBm. In other words, the Mobile Station's maximum transmit power is 14 dB lower than the small cell's transmit power. This implies that the Mobile Station would be transmitting at least 25 times weaker signal than a small cell. Furthermore, the use of power control and distribution of Mobile Stations in a given cell would lead to the actual transmit power of the Mobile Station less than 23 dBm. Hence, many more than 4.75 billion Mobile Stations can be supported in a 200 square kilometer area.

Additionally, we note that more 5G transmitters can be supported than the number of transmitters predicted here due to the worst-case interference scenario assumed in the analysis.

[29] Detailed calculations of the values shown in Table 2 using the steps outlined above are contained in Appendix III.

[30] In case of the macro cells, the OOBE EIRP has a non-linear relationship with receive bandwidth due to different attenuation levels within the receive bandwidth. In case of fixed, 5W small cells, the OOBE has a linear relationship with the receive bandwidth, making the number of supportable small cell Base Station transmitters independent of the receive bandwidth.

IV. Summary of the RAS Interference Analysis: 5G Mobile Stations as Transmitters

The radius of the exclusion zone around an RAS receiver specified in Section III assumes that the worst-case interference is caused by a high-power Base Station (BS) transmitter and not by multiple low-powered Mobile Station (MS) transmitters. The analysis performed in this Section determines the number of MSs that would generate the same amount of interference as a high-power BS. As long as practical deployments involve fewer simultaneously transmitting MSs than the number of supportable MSs predicted by the analysis, the exclusion zone around an RAS receiver estimated for BS transmitters would still be valid and 5G Base Stations or Mobile Stations can co-exist harmoniously with RAS.

High-Level Analysis Approach

This analysis aims to answer the following question: How many Mobile Station transmitters are equivalent to one high-power Base Station transmitter?

The key steps for the MS analysis are specified below:

1. Calculate the amount of interference generated at an RAS receiver (e.g., x mW) due to full-power transmission from one BS.
2. Calculate the amount of interference generated at an RAS receiver (e.g., y mW) due to power-controlled transmission from one MS located on the cell-edge of a 5G sector between the RAS and BS.
3. Estimate the number of simultaneous MSs on the cell-edge of a 5G sector within this region (x/y).

Assumptions

- 5G link budget (i.e., maximum allowable path loss): 129 dB
- 5G cell-edge data rate: 50 Mbps
- OOBE EIRP of an MS transmitter: -27.8 dBm (corresponding to 43 dBm in-band EIRP of the MS and out-of-band to in-band attenuation of 60 dB)

***The analysis finds that about 250 simultaneously transmitting Mobile Stations in a macro cell can be supported at the cell-edge*, which is about 2 km from the BS and 34 km from the RAS, as shown in Figure 2 below.** In practice, a 5G cell may be much smaller than 2 km depending upon the deployment scenario. Note that the exclusion zone can be enlarged to accommodate even more MSs (as noted in Table 3 below) and the impact of the MSs can be entirely prevented from operating inside the exclusion zone by turning off the sector toward the RAS receiver. Many more that 250 cell-edge Mobile Stations can be supported in the case of outdoor and indoor small cell deployments. Furthermore, the use of power control and distribution of Mobile Stations in a given cell would lead to the actual transmit power of the Mobile Station being much less than the maximum transmit power assumed here. Note that the analysis carried out here assumes the worst-case interference scenario, where the path between a 5G Mobile Station transmitter and an RAS receiver is unobstructed by intervening objects such as vegetation and buildings. In practice, these objects would significantly weaken the actual interference experienced by an RAS receiver, For example, and as noted above, interference from a 5G Mobile Station transmitter could easily attenuate by 20 dB to 30 dB (i.e., 100 to 1,000 times weaker) due to the presence of such intervening objects. Hence, 100 times more Mobile Stations (e.g., 25,000 instead of 250) can potentially be supported in practice.

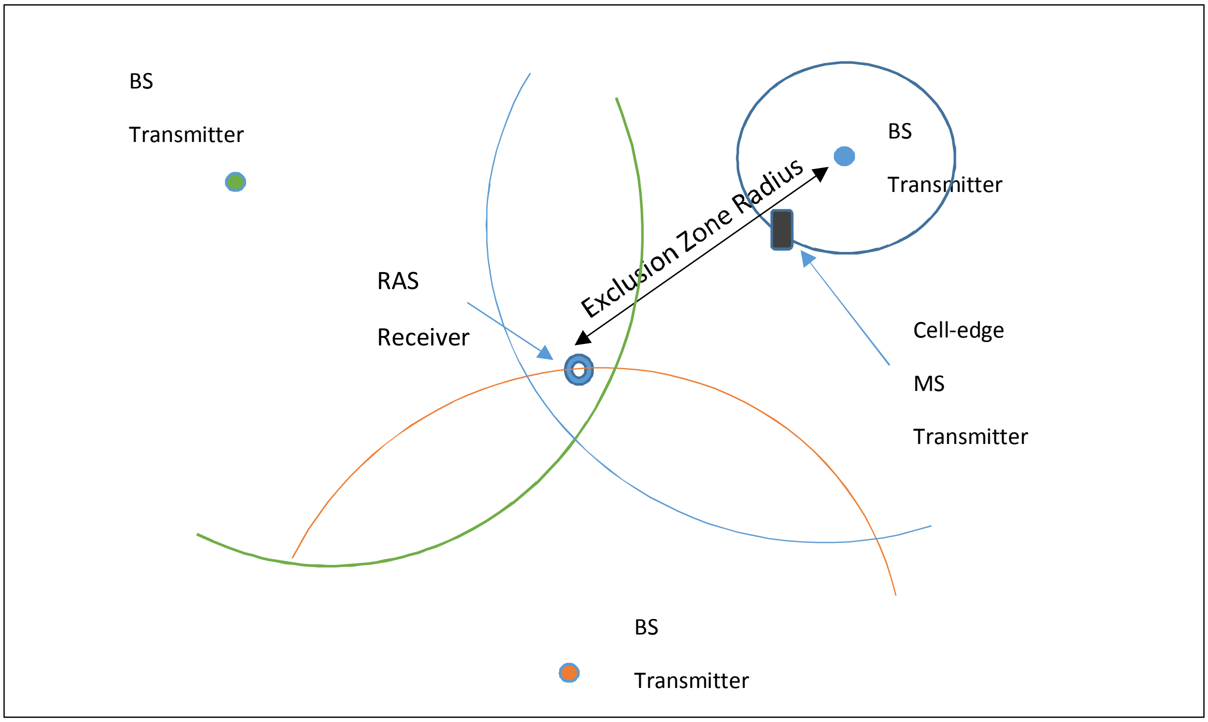


Figure 2. 5G Deployment Scenario for RAS Exclusion Zone

Table 3. Influence of the Exclusion Zone Size on Supportable MSs

Radius of the Exclusion Zone (km)	Number of Simultaneous Cell-Edge MSs
36	**255**
40	**320**
50	**510**

In today's network, tens of devices are scheduled for uplink transmission simultaneously. Hence, considering that about 250 cell-edge MSs can be simultaneously supported without any transmit beamforming in the uplink, many more than 250 MSs distributed across a macro sector can be supported with transmit beamforming in the uplink.

V. Interference Mitigation Techniques

The analyses in this paper uses worst-case interference scenarios and assumptions. There are several factors that would mitigate interference in practice, leading to requirements of smaller protection zones around RAS receivers and an even greater number of supportable 5G transmitters while protecting EESS/SRS receivers. For example, 5G is considering several candidate waveforms (e.g., Universal Filtered Multi Carrier (UFMC) and Filter Bank Multi Carrier (FBMC)) as an alternative to currently used Orthogonal Frequency Division Multiplexing (OFDM)-based waveform in 4G LTE networks. Such waveforms are expected to reduce OOBE, reducing the amount of interference caused to adjacent frequency bands.[31]

While our analysis has assumed 40 dB reduction toward an RAS receiver, larger attenuation would be possible to achieve due to massive MIMO in the mmW spectrum.[32] In general, it is easier to achieve very deep nulls using an antenna array than to achieve a high-gain beam. Null steering can be built into the array algorithms.

This analysis primarily considers high-powered macro Base Station transmitters. 5G is expected to use numerous indoor and outdoor small cells. Indoor small cells will significantly attenuate 5G signals (e.g., by 15 dB to 20 dB) and reduce interference to RAS, EESS, and SRS receivers.

This analysis also assumes free-space path loss between the transmitter and the receiver. In practice, vegetation and shadow fading due to natural obstructions and man-made structures would further weaken 5G signals by the time these signals reach the receiver, as will atmospheric attenuation. Vegetation attenuation can be drastic with foliage losses of 1.3 – 2.0 dB/m for the first 30m of vegetation.[33]

Finally, there is more to interference mitigation than just the physical layer. 5G will be composed of heterogeneous systems dynamically operating across and in conjunction with different bands. Hence, if the network knows the position of the user equipment, it can transfer the communications link to another band as needed.

[31] *See* Anritsu Waveform Analysis; *Baltar & Waldhauser*.

[32] *See* IEEE Beamforming Survey.

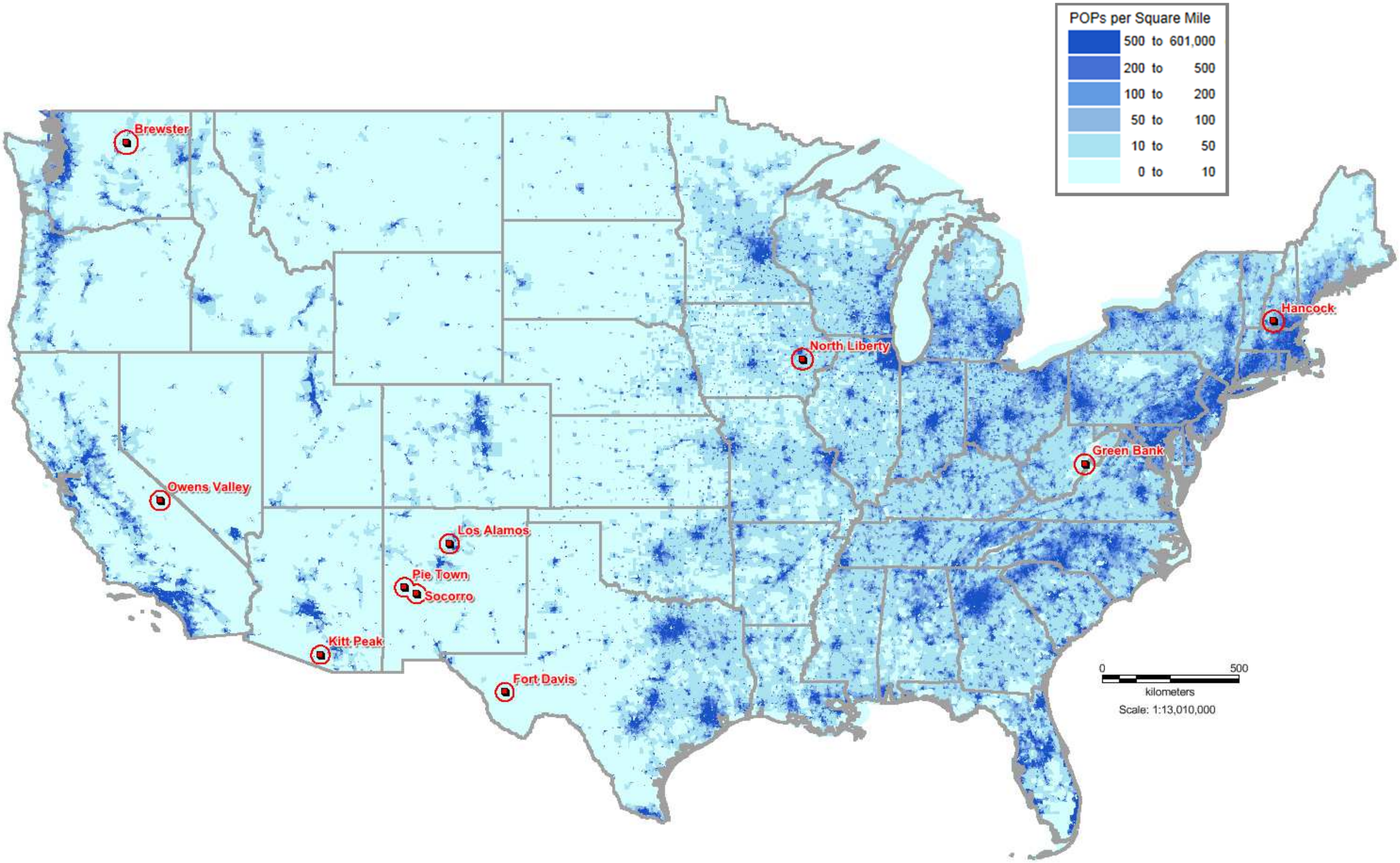
[33] *See* F. K. Schwering, E. J. Violette & R. H. Espeland, *Millimeter-wave propagation in vegetation: Experiments and theory*, 26 IEEE TRANSACTIONS ON GEOSCIENCE AND REMOTE SENSING 355-67 (May 1988).

Appendix I

Radioastronomy Sites Using the 31.1-31.8 GHz Band

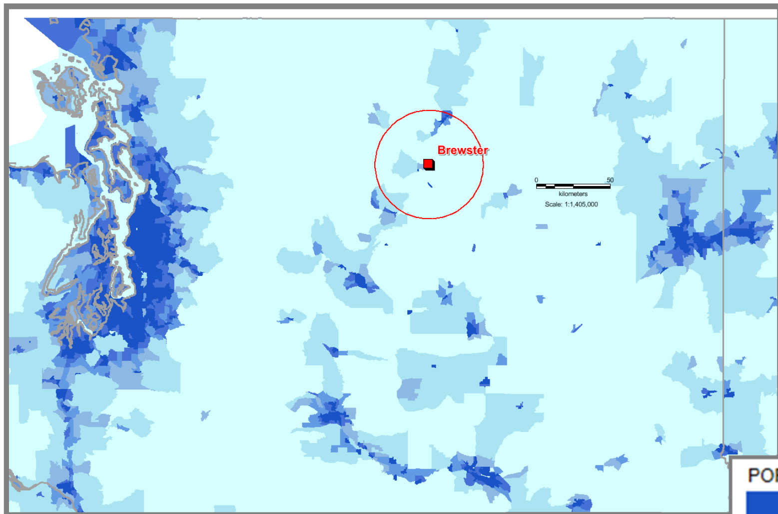
Radioastronomy Sites using the 31.3-31.8 GHz Band in CoNUS

(36.1 km exclusion zone shown in red)

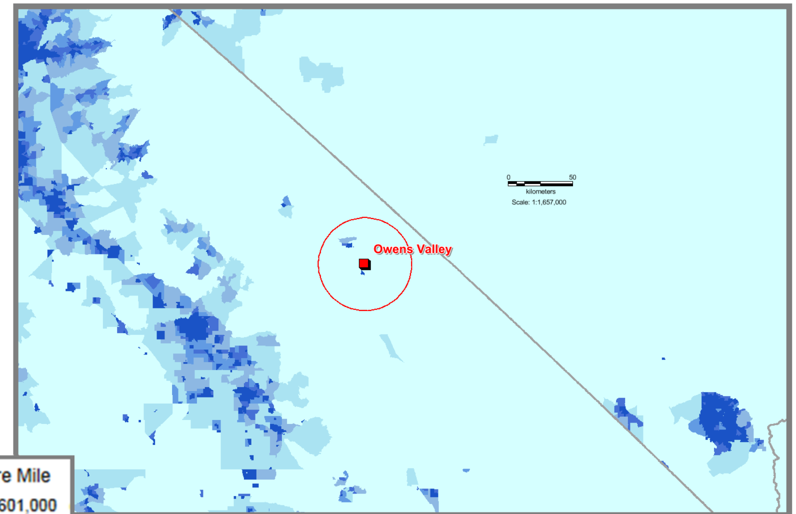


Radioastronomy Sites using the 31.3-31.8 GHz Band (1 of 3)

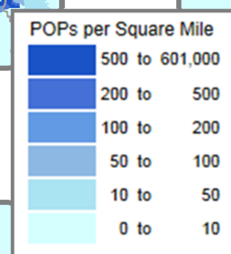
(36.1 km exclusion zone shown in red)

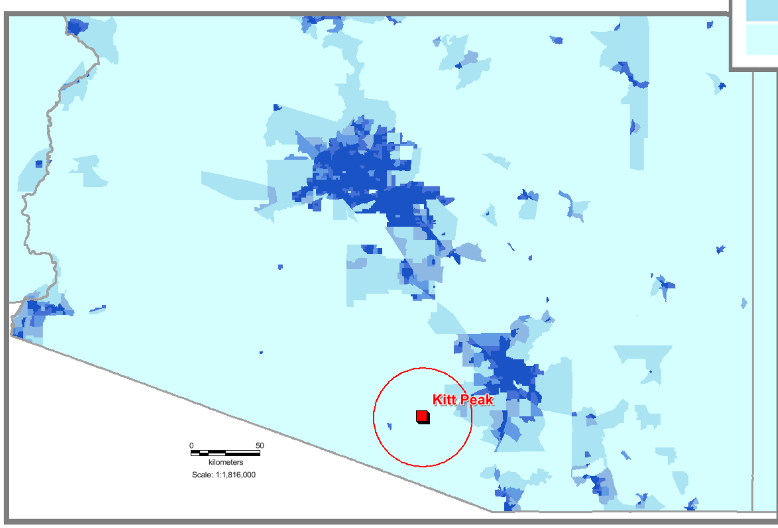


Brewster, WA

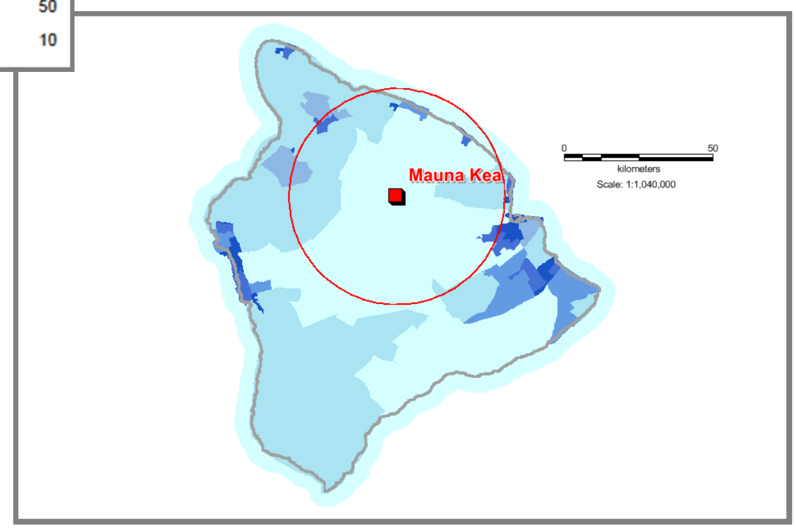


Owens Valley, CA





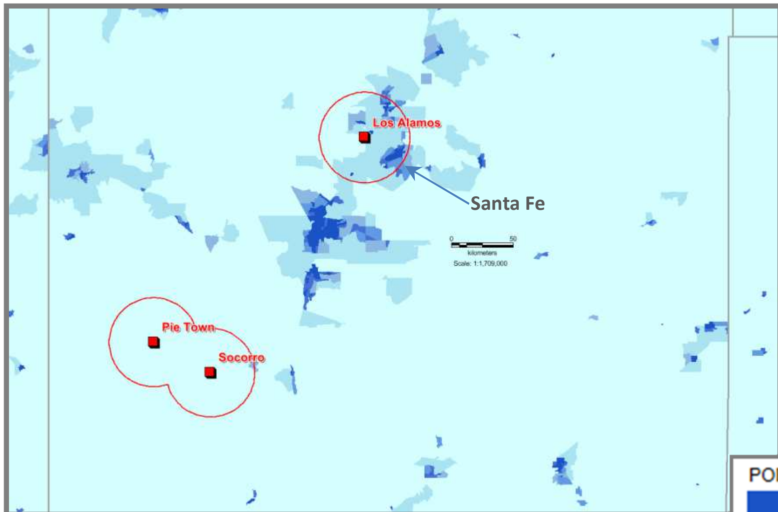
Kitt Peak, AZ



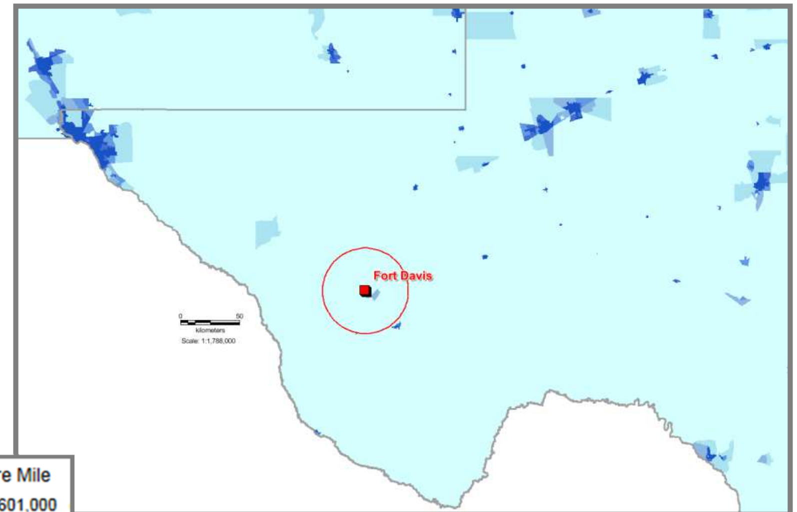
Mauna Kea, HI

Radioastronomy Sites using the 31.3-31.8 GHz Band (2 of 3)

(36.1 km exclusion zone shown in red)

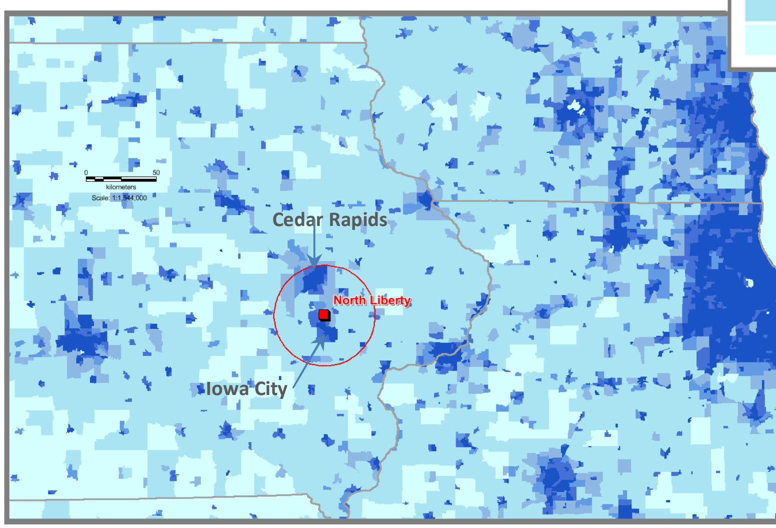


Los Alamos, Pie Town & Socorro, NM

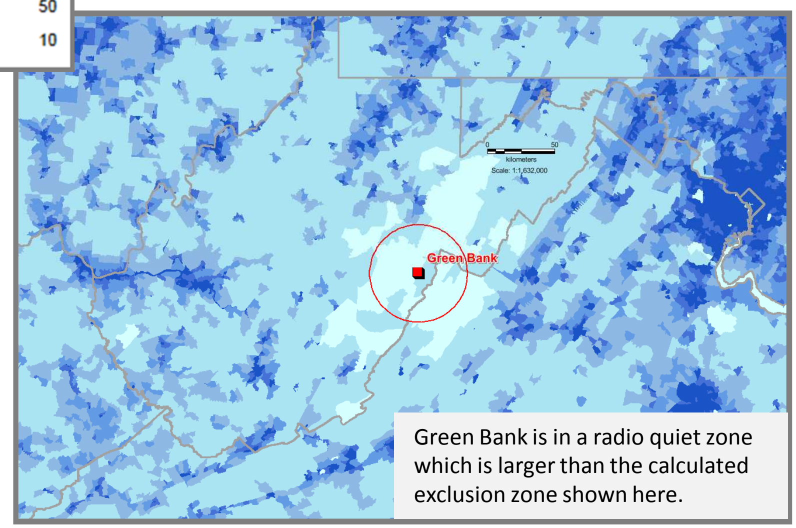


Fort Davis, TX

POPs per Square Mile
500 to 601,000
200 to 500
100 to 200
50 to 100
10 to 50
0 to 10



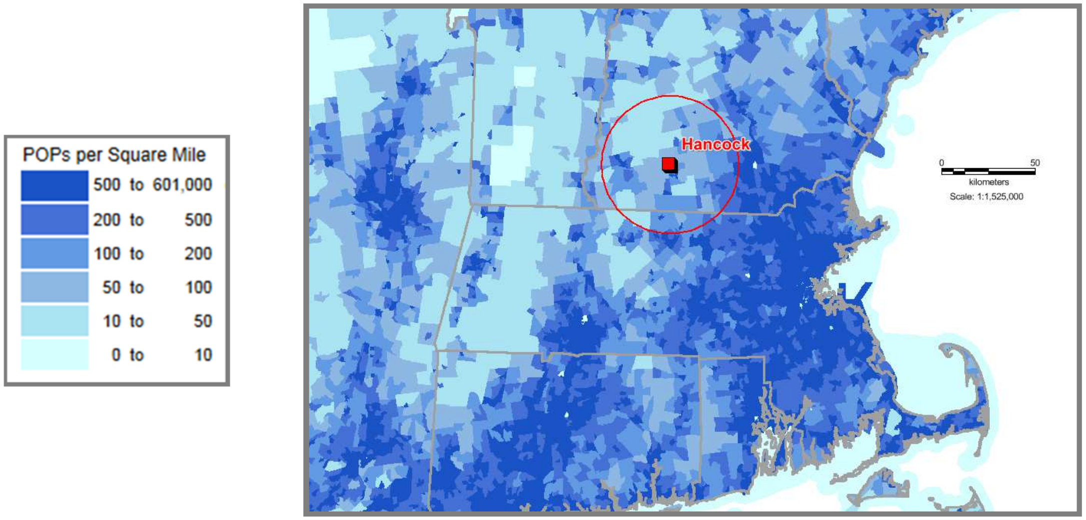
North Liberty, IA



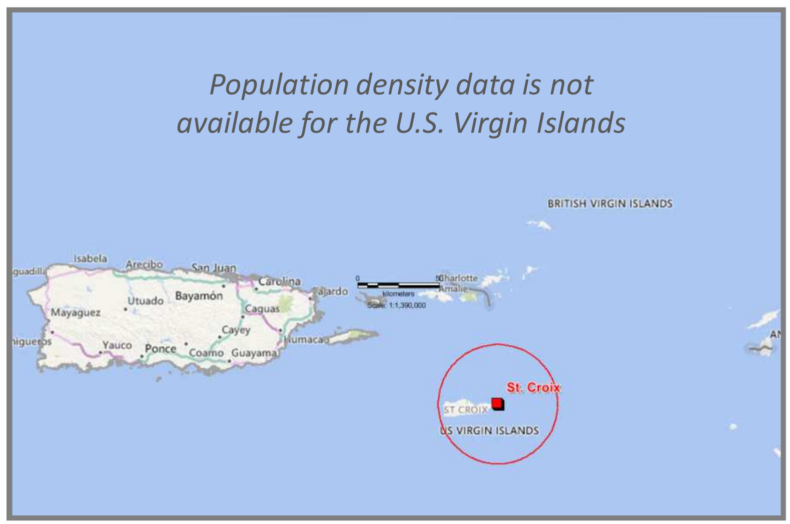
Green Bank, WV

Radioastronomy Sites using the 31.3-31.8 GHz Band (3 of 3)

(36.1 km exclusion zone shown in red)



Hancock, NH



St. Croix, VI

Appendix II

RAS Exclusion Zone Calculations

RAS Exclusion Zone Calculations - Macrocells with Beamforming

RAS Receiver Interference Threshold		
Parameter and Units	**Value**	**Comments**
Reference interference threshold for reference (dBW)	-192	ITU-R RA.769-2, Table 1, 31.55 GHz frequency
Reference interference threshold for reference (dBm)	-162	dBm= dBW + 30 dB
Reference receiver bandwidth for reference interference threshold (MHz)	500	ITU-R RA.769-2, Table 1, 31.55 GHz frequency
Typical (i.e., actual) receiver bandwidth (MHz)	**500**	Worst case for macrocells; wider receiver bandwidth results in smaller exclusion zones
Target interference level at the receiver in the receiver channel bandwidth (dBm)	**-162.00**	This is the maximum amount of interference power that can be tolerated in the receive channel bandwidth of the RAS receiver
Target interference level at the receiver (dBm/MHz)	**-188.99**	
Target interference level for one transmitter at the receiver in the receiver channel bandwidth (dBm)	-162.00	

5G Transmitter Characteristics		
Parameter and Units	**Value**	**Comments**
Transmit Channel Bandwidth for Interference Calculations (MHz)	300	Options: (1) 75 MHz if only Band B2 (31.225-31.30 GHz) is used (2) 100 MHz reference bandwidth and (3) 300 MHz if all of A3 band (31.075-31.225 GHz), B1 band (31.00-31.075 GHz), and B2 band (31.225-31.30 GHz) are fully used
Transmitter Selection for Analysis	BS	BS, MS, or TS
First 10% of channel bandwidth from the channel edge (MHz)	30	
Remaining (90% of) channel bandwidth from the channel edge (MHz)	470	
Max allowed EIRP of the Transmitter in the first 10% of channel bandwidth from the channel edge (dBm/MHz)	-5	
Max allowed EIRP of the Transmitter in the remanining 90% of channel bandwidth from the channel edge (dBm/MHz)	-13	
Nominal EIRP of the Transmitter in the Receiver Bandwidth (dBm)	14.71	This has contributions from two different dBm/MHz limits
Fraction of radio resources used for overhead signals	0.25	At any instant, up to 25% (worst-case) radio resouces are used for sector (cell)-wide non-beamformed transmission at a regular power level. LTE example: reference signals (2/12), sync signals less than 1%, physical broadcast channel 6/50. **This is Work-in-Progress within 3GPP and hence it is an assumption at this time.**
Fraction of radio resources used for non-overhead functions (e.g., a radio channel carrying traffic)	0.75	
Average attenuation toward the RAS receiver for overhead functions (dB)	15.00	Down-tilting and azimuth changes of antennas can easily help achieve this attenuation.
Average attenuation toward the RAS receiver for non-overhead functions (dB)	40.00	
Contribution of overhead signals to interference (mW)	0.23	
Contribution of beamformed non-overhead resources to interference (mW)	2.22E-03	
Effective EIRP of the Transmitter in the Receiver Bandwidth (dBm)	-6.27	This is dominated by overhead signals.
Distance-dependent atmospheric loss (dBm)	**0**	Atmospheric loss is assumed to be zero (worst case)
EIRP of the Transmitter adjusted for distance-dependent atmospheric loss (dBm)	**-6.27**	
Number of Simultaneously Active Base Station transmitters	3	

Exclusion Zone Calculations		
Parameter and Units	**Value**	**Comments**
Received Power, Prx, in the Overlapping Bandwidth (dBm) (target for 3 transmitters)	-166.77	
Receive Antenna Gain for a RAS Receiver (dBi) (Gr)	-10	ITU-R RA.769-2. "…since the side lobe gain, as represented by the model, varies from 32 to –10 dBi as a function of this angle."
Carrier frequency (center of the RAS bands) (Hz)	31,550,000,000	Center of (31.3 to 31.8 GHz) for RAS, EESS, and SRS
Wavelength (m)	0.0095	
Radius of an Exclusion Zone for a Hypothetical In-band RAS Receiver (m)	25349	path loss (when negative: Prx=Ptx+Lp), Lp=20*log10(lambda/(4*pi*d)). Path loss (when positive: Prx=Ptx-Lp), Lp=20*log10(4*pi*d/lambda). Distance d=(lambda/(4*pi))*10^((EIRP+Gr-Prx)/20)
Radius of an Exclusion Zone for a Hypothetical In-band RAS Receiver (km)	**25.3**	
Radius of an Exclusion Zone for a Hypothetical In-band RAS Receiver (miles)	**15.8**	
Conclusion: Beamforming and traditional RF optimization will enable 5G cellular networks to co-exist with RAS receivers.		

RAS Exclusion Zone Calculations - Small Cells with Beamforming

RAS Receiver Interference Threshold		
Parameter and Units	**Value**	**Comments**
Reference interference threshold for reference (dBW)	-192	ITU-R RA.769-2, Table 1, 31.55 GHz frequency
Reference interference threshold for reference (dBm)	-162	dBm= dBW + 30 dB
Reference receiver bandwidth for reference interference threshold (MHz)	500	ITU-R RA.769-2, Table 1, 31.55 GHz frequency
Typical (i.e., actual) receiver bandwidth (MHz)	**500**	Per ITU-R SM.2092, one band for RAS is 31.3-31.5 GHz, making the maximum bandwidth 200 MHz. Another band is 31.5-31.8 GHz, making the maximum bandwidth 300 MHz. If the radio telescope receiver combines the two adjacent bands, it could be using the maximum channel bandwidth of 500 MHz.
Target interference level at the receiver in the receiver channel bandwidth (dBm)	**-162.00**	This is the maximum amount of interference power that can be tolerated in the receive channel bandwidth of the RAS receiver
Target interference level at the receiver per MHz (dBm/MHz)	**-188.99**	
Target interference level for one transmitter at the receiver in the receiver channel bandwidth (dBm)	-162.00	

5G Transmitter Characteristics		
Parameter and Units	**Value**	**Comments**
Transmit Channel Bandwidth for Interference Calculations (MHz)	300	Options: (1) 75 MHz if only Band B2 (31.225-31.30 GHz) is used (2) 100 MHz reference bandwidth and (3) 300 MHz if all of A3 band (31.075-31.225 GHz), B1 band (31.00-31.075 GHz), and B2 band (31.225-31.30 GHz) are fully used
Transmitter Selection for Analysis	BS	BS, MS, or TS
In-band Maximum Base Station (BS) Transmit Power (dBm per 100 MHz)	75	FCC 16-89, Effective Isotropic Radiated Power (EIRP) (includes impact of transmit antenna gain but not any beamforming)
EIRP of Base Station (BS) Transmit Power per MHz (dBm per MHz)	55	FCC 16-89, Effective Isotropic Radiated Power (EIRP) (includes impact of transmit antenna gain but not any beamforming)
EIRP of the Transmitter Selected for Analysis (dBm/MHz)	55	
OOBE within 10% of the channel edge (dBm/MHz)	-5	FCC 16-89, ¶ 308
Attenuation of the signal (dB) from in-band to out-of-band (dB)	60	
Typical small cell EIRP (W)	5	
Typical small cell EIRP (dBm)	36.99	-23
OOBE of the Small Cell Transmitter (dBm)	-23.01	
OOBE of Small Cell Cell Transmit Power per MHz (dBm per MHz)	-47.78	Independent of Rx Bandwidth
Nominal EIRP of the Transmitter in the Overlapping Bandwidth (dBm)	-20.79	
Fraction of radio resources used for overhead signals	0.25	At any instant, up to 25% (worst-case) radio resouces are used for sector (cell)-wide non-beamformed transmission at a regular power level. LTE example: reference signals (2/12), sync signals less than 1%, physical broadcast channel 6/50.
Fraction of radio resources used for non-overhead functions (e.g., a radio channel carrying traffic)	0.75	
Average attenuation toward the RAS receiver for overhead functions (dB)	15.00	Down-tilting and azimuth changes of antennas can easily help achieve this attenuation.
Average attenuation toward the RAS receiver in the un-intended direction due to beamforming in the intended direction (dB)	40.00	
Contribution of overhead signals to interference (mW)	6.59E-05	
Contribution of beamformed non-overhead resources to interference (mW)	6.25E-07	
Effective EIRP of the Transmitter in the Overlapping Bandwidth (dBm)	-41.77	
Distance-dependent atmospheric loss (dBm)	**0**	Atmospheric loss is assumed to be zero (worst case)
EIRP of the Transmitter adjusted for distance-dependent atmospheric loss (dBm)	**-41.77**	
Number of Simultaneously Active Base Station transmitters	10000	

Exclusion Zone Calculations		
Parameter and Units	**Value**	**Comments**
Received Power, Prx, in the Overlapping Bandwidth (dBm) (target for 10000 transmitters	-202.00	
Receive Antenna Gain for a RAS Receiver (dBi) (Gr)	-10	ITU-R RA.769-2. "...since the side lobe gain, as represented by the model, varies from 32 to –10 dBi as a function of this angle."
Carrier frequency (center of the RAS bands) (Hz)	31,550,000,000	Center of (31.3 to 31.8 GHz) for RAS, EESS, and SRS
wavelength (m)	0.0095	
Radius of an Exclusion Zone for a Hypothetical In-band RAS Receiver (m)	24566	path loss (when negative: Prx=Ptx+Lp), Lp=20*log10(lambda/(4*pi*d)). Path loss (when positive: Prx=Ptx-Lp), Lp=20*log10(4*pi*d/lambda). Distance d=(lambda/(4*pi))*10^((EIRP+Gr-Prx)/20)
Radius of an Exclusion Zone for a Hypothetical In-band RAS Receiver (km)	**24.6**	Results are the same for all receiver bandwidth assumptions
Radius of an Exclusion Zone for a Hypothetical In-band RAS Receiver (miles)	**15.3**	
Conclusion: Small cells with small coverage and beamforming can easily accommodate RAS receivers.		

Appendix III

EESS Calculations

EESS Calculations - Macrocells with Beamforming

EESS Receiver Interference Threshold		
Parameter and Units	**Value**	**Comments**
Reference interference threshold for reference (dBW per 100 MHz)	-163	ITU-R SM.2092, Section 9
Reference interference threshold for reference (dBm per 100 MHz)	-133	dBm= dBW + 30 dB
Reference receiver bandwidth for reference interference threshold (MHz)	100	ITU-R SM.2092, Section 9
Typical (i.e., actual) receiver bandwidth (MHz)	200	ITU-R SM.2092, Section 9, mentions that two split bands, 31.3-31.5 GHz band and 31.5-31.8 GHz, allow a comparison of the measurements conducted in the two sub-bands to check the quality of the data.
Target interference level at the input to the receive antenna in the receiver channel bandwidth (dBm)	-129.99	This is the maximum amount of interference power that can be tolerated in the receive channel bandwidth of the EESS receiver from all sources of interference
Target interference level at the input to the receive antenna per MHz (dBm/MHz)	**-153.00**	

EESS Satellite Characteristics		
Parameter and Units	**Value**	**Comments**
Receive antenna gain for the satellite-based receiver (dBi)	45	ITU-R SM.2092, Section 9
Satellite altitude (km)	850	ITU-R SM.2092, Section 9
Surface area on the Earth covered by the EESS satellite's sensor "pixel" (square kilometer)	201	ITU-R SM.2092, Section 9
Operating carrier frequency (MHz)	31550	Center of the EESS band
Wavelength (m)	0.0095	
LOS path loss between an earth transmitter and the EESS satellite (dB)	181.01	

5G Transmitter Characteristics		
Parameter and Units	**Value**	**Comments**
Transmit Channel Bandwidth for Interference Calculations (MHz)	300	Options: (1) 75 MHz if only Band B2 (31.225-31.30 GHz) is used (2) 100 MHz reference bandwidth and (3) 300 MHz if all of A3 band (31.075-31.225 GHz), B1 band (31.00-31.075 GHz), and B2 band (31.225-31.30 GHz) are fully used
First 10% of channel bandwidth from the channel edge	30	This is part of the transition band
Remaining (90% of) channel bandwidth from the channel edge	170	This is part of the transition band
EIRP of the OOBE-compliant Transmitter in the first 10% of channel bandwidth from the channel edge (dBm/MHz)	-5	FCC 16-89, ¶ 308
EIRP of the OOBE-compliant Transmitter in the remaining 90% of channel bandwidth from the channel edge (dBm/MHz)	-13	FCC 16-89, ¶ 308
Nominal EIRP of a single OOBE-compliant Transmitter in the Receiver Bandwidth (dBm)	13.80	
Fraction of radio resources used for overhead signals	0.25	At any instant, up to 25% (worst-case) radio resouces are used for sector (cell)-wide non-beamformed transmission at a regular power level. LTE example: reference signals (2/12), sync signals less than 1%, physical broadcast channel 6/50. **This is Work-in-Progress within 3GPP and hence it is an assumption at this time.**
Fraction of radio resources used for non-overhead functions (e.g., a radio channel carrying traffic)	0.75	
Average attenuation toward the EESS receiver for overhead functions (dB)	15.00	Down-tilting of antennas can easily help achieve this attenuation.
Average attenuation toward the RAS receiver for non-overhead functions (dB)	40.00	
Contribution of overhead signals to interference (mW)	0.19	
Contribution of beamformed non-overhead resources to interference (mW)	1.80E-03	

Effective EIRP of the Transmitter in the Overlapping Bandwidth (dBm)	-7.17	This is dominated by overhead signals.
Distance-dependent atmospheric loss (dBm)	**0**	Atmospheric loss is assumed to be zero (worst case)
EIRP of the Transmitter adjusted for distance-dependent atmospheric loss (dBm)	-7.17	

Number of Transmitters Calculation		
Parameter and Units	**Value**	**Comments**
Interference power at the receive antenna of the EESS satellite from a single OOBE-compliant transmitter (dBm)	-188.18	
Maximum allowed interference power, Pmax, in the Receiver Bandwidth at the input to the EESS receiver antenna (dBm)	-129.99	
Maximum number of OOBE-compliant Transmitters that can be Supported in an EESS satellite beam (with suitable beamforming and antenna adjustments)	**659,968**	

EESS Calculations - Small Cells with Beamforming

EESS Receiver Interference Threshold		
Parameter and Units	**Value**	**Comments**
Reference interference threshold for reference (dBW per 100 MHz)	-163	ITU-R SM.2092, Section 9
Reference interference threshold for reference (dBm per 100 MHz)	-133	dBm= dBW + 30 dB
Reference receiver bandwidth for reference interference threshold (MHz)	100	ITU-R SM.2092, Section 9
Typical (i.e., actual) receiver bandwidth (MHz)	**500**	ITU-R SM.2092, Section 9, mentions that two split bands, 31-31.3 GHz band and 31.5-31.8 GHz, allow a comparison of the measurements conducted in the two sub-bands to check the quality of the data. So, 300 MHz is a very good assumption.
Target interference level at the input to the receive antenna in the receiver channel bandwidth (dBm)	-126.01	This is the maximum amount of interference power that can be tolerated in the receive channel bandwidth of the EESS receiver from all sources of interference
Target interference level at the input to the receive antenna per MHz (dBm/MHz)	**-153.00**	

EESS Satellite Characteristics		
Parameter and Units	**Value**	**Comments**
Receive antenna gain for the satellite-based receiver (dBi)	45	ITU-R SM.2092, Section 9
Satellite altitude (km)	850	ITU-R SM.2092, Section 9
Surface area on the Earth covered by the EESS satellite's sensor "pixel" (square kilometer)	201	ITU-R SM.2092, Section 9
Operating carrier frequency (MHz)	31550	Center of the EESS band
Wavelength (m)	0.0095	
LOS path loss between an earth transmitter and the EESS satellite (dB)	181.01	

5G Transmitter Characteristics		
Parameter and Units	**Value**	**Comments**
Transmit Channel Bandwidth for Interference Calculations (MHz)	300	Options: (1) 75 MHz if only Band B2 (31.225-31.30 GHz) is used (2) 100 MHz reference bandwidth and (3) 300 MHz if all of A3 band (31.075-31.225 GHz), B1 band (31.00-31.075 GHz), and B2 band (31.225-31.30 GHz) are fully used
Transmitter Selection for Analysis	BS	BS, MS, or TS
In-band Maximum Base Station (BS) Transmit Power (dBm per 100 MHz)	75	FCC 16-89, Effective Isotropic Radiated Power (EIRP) (includes impact of transmit antenna gain but not any beamforming)
EIRP of Base Station (BS) Transmit Power per MHz (dBm per MHz)	55	FCC 16-89, Effective Isotropic Radiated Power (EIRP) (includes impact of transmit antenna gain but not any beamforming)
EIRP of the Transmitter Selected for Analysis (dBm/MHz)	55	
OOBE within 10% of the channel edge (dBm/MHz)	-5	FCC 16-89, ¶ 308
Attenuation of the signal (dB) from in-band to out-of-band (dB)	60	
Typical small cell EIRP (W)	5	
Typical small cell EIRP (dBm)	36.99	-23
OOBE of the Small Cell Transmitter (dBm)	-23.01	
OOBE of Small Cell Cell Transmit Power per MHz (dBm per MHz)	-47.78	Independent of Rx Bandwidth
Nominal EIRP of the Transmitter in the Overlapping Bandwidth (dBm)	-20.79	
Fraction of radio resources used for overhead signals	0.25	At any instant, up to 25% (worst-case) radio resouces are used for sector (cell)-wide non-beamformed transmission at a regular power level. LTE example: reference signals (2/12), sync signals less than 1%, physical broadcast channel 6/50.

Fraction of radio resources used for non-overhead functions (e.g., a radio channel carrying traffic)	0.75	
Average attenuation toward the EESS receiver for overhead functions (dB)	15.00	Down-tilting and azimuth changes of antennas can easily help achieve this attenuation.
Average attenuation toward the EESS receiver in the un-intended direction due to beamforming in the intended direction (dB)	40.00	
Contribution of overhead signals to interference (mW)	6.59E-05	
Contribution of beamformed non-overhead resources to interference (mW)	6.25E-07	
Effective EIRP of the Transmitter in the Overlapping Bandwidth (dBm)	-41.77	
Distance-dependent atmospheric loss (dBm)	**0**	Atmospheric loss is assumed to be zero (worst case)
EIRP of the Transmitter adjusted for distance-dependent atmospheric loss (dBm)	-41.77	

Number of Transmitters Calculation		
Parameter and Units	**Value**	**Comments**
Interference power at the receive antenna of the EESS satellite from a single OOBE-compliant transmitter (dBm)	-222.78	
Maximum allowed interference power, Pmax, in the Receiver Bandwidth at the input to the EESS receiver antenna (dBm)	-126.01	
Maximum number of OOBE-compliant Transmitters that can be Supported in an EESS satellite beam (with suitable beamforming and antenna adjustments)	**4,754,713,796**	
	4.755	billion

27.5-29.5 GHz Band Plan for Europe and U.S.

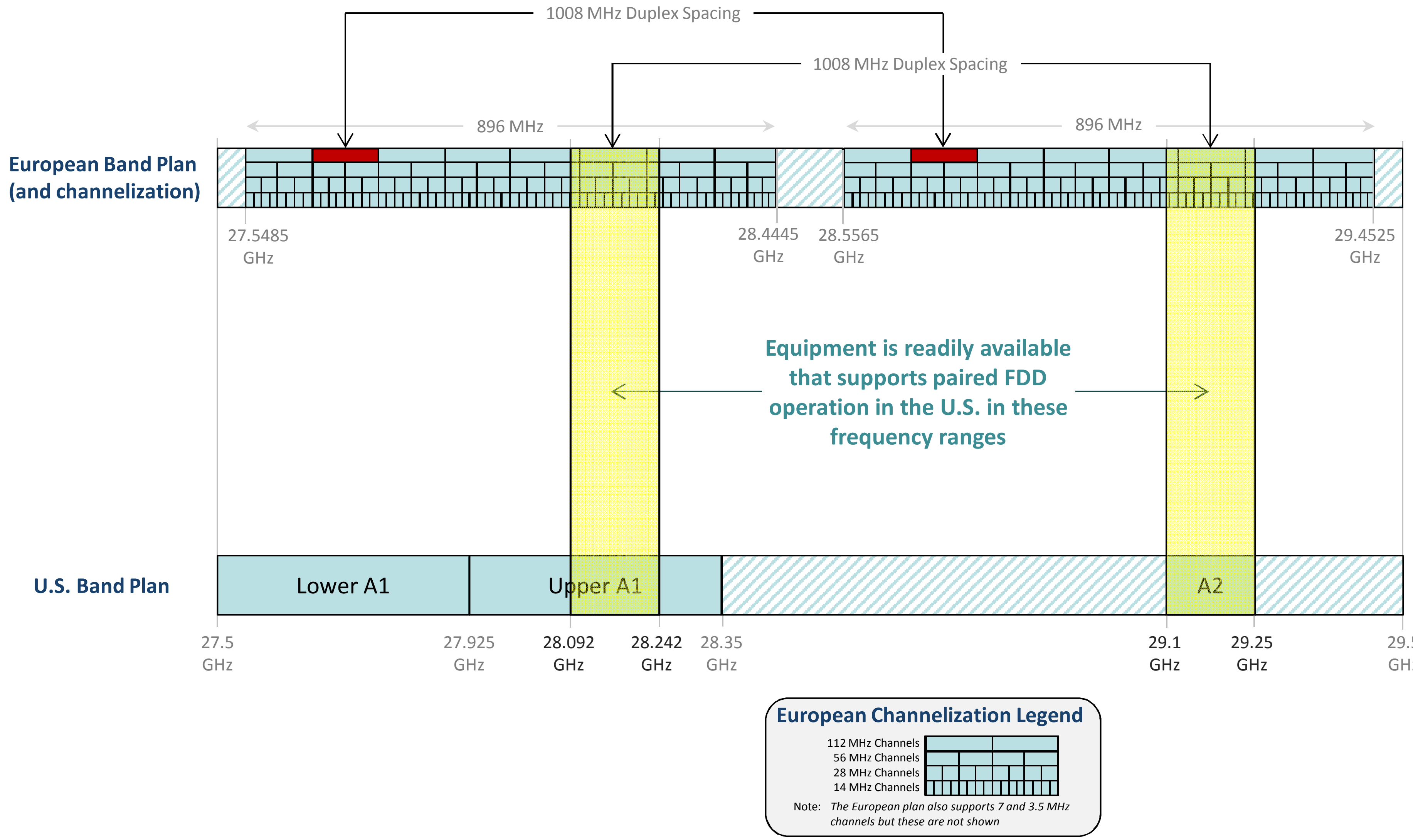
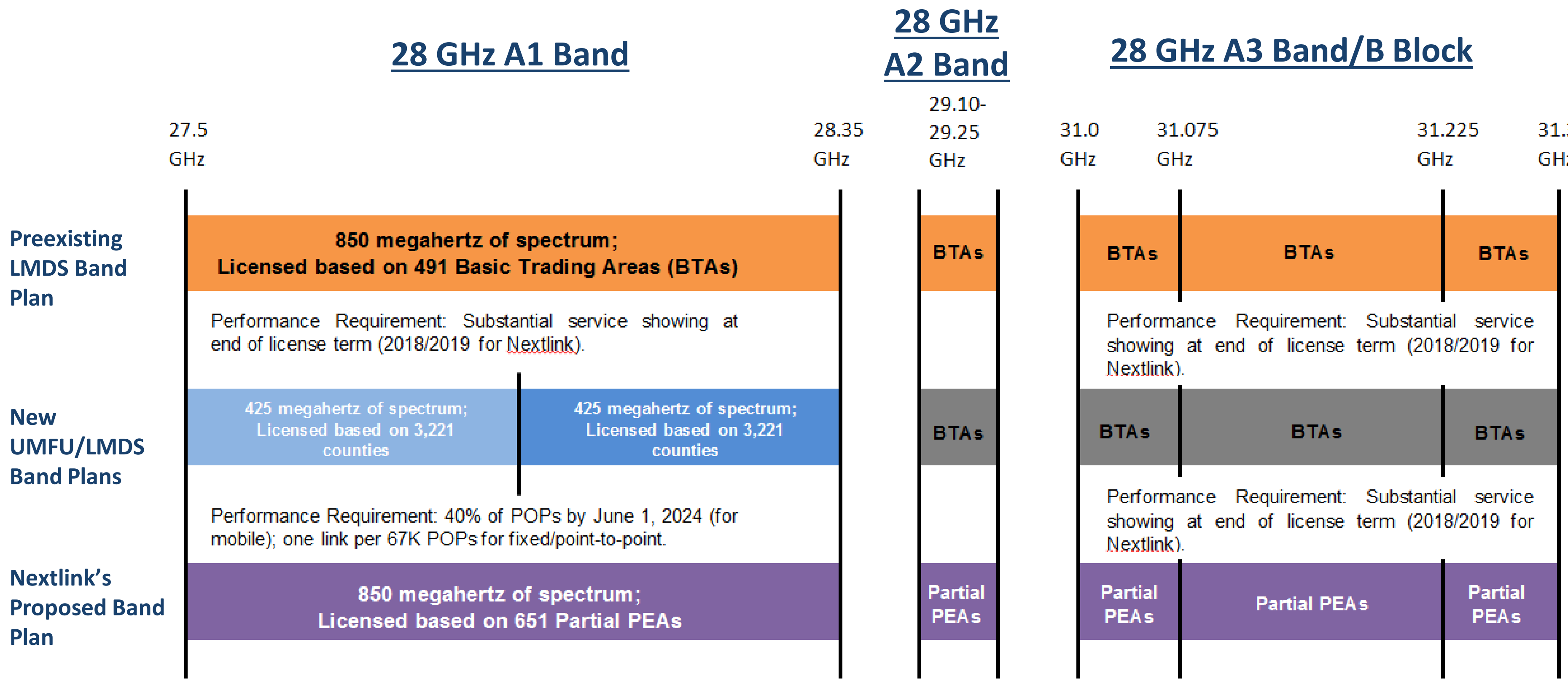


Exhibit B

LMDS/UMFU Band Plan Rules vs. Nextlink Proposal



Nextlink Proposal:

- **Create regulatory parity among new entrants and incumbent licensees, as well as across LMDS band segments, by assigning UMFUS rights to the entire band and adopting the same performance deadlines across the LMDS band for all licensees.**
- **Alternatively, the FCC could set a harmonized interim benchmark to be met in 2024 or six years after an auction of new UMFU licenses (whichever is later) and a final, uniform deadline (for all LMDS band segments) at the end of new UMFU licensees' initial terms.**

Note: Diagram not drawn to scale.

Texas

32 Basic Trading Areas versus 254 Counties!